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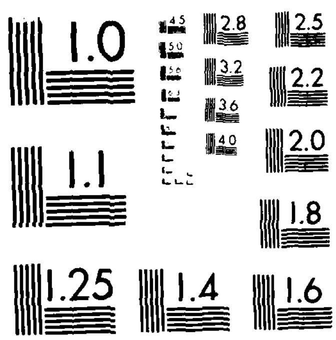

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EVALUATION OF A PASSENGER MASK MODIFIED WITH A REBREATHER BAG FOR PROTECTION FROM SMOKE AND FUMES

E. A. Higgins, J. T. Saldivar, P. J. Lyne,
and G. E. Funkhouser

Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, Oklahoma

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16. Abstract

A series of experiments were conducted in an altitude chamber at ground level, 8,000 ft, 14,000 ft, and 21,500 ft, both with and without exercise, to evaluate the potential for providing protection from smoke and fumes for airline passengers while wearing a standard continuous-flow passenger mask modified by the addition of a rebreather bag. It was determined that it would provide increased protection for those individuals who had tidal volumes of 1.5 L or less. However, it would not function properly for those individuals who had tidal volumes greater than 1.5 L. Either the carbon dioxide levels were too great (above 15 mm Hg partial pressure) or the rebreather bag collapsed. These results indicate that the addition of the rebreather bag to the passenger mask has the potential for providing protection from smoke and fumes, but the system must have appropriately balanced valve resistances and appropriately sized valve openings. This critical balance has not yet been achieved for those individuals with large tidal volumes.

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EVALUATION OF A PASSENGER MASK MODIFIED WITH A REBREATHER BAG FOR PROTECTION FROM SMOKE AND FUMES

INTRODUCTION

It is now possible to provide protection from smoke and fumes for both flight deck and cabin crewmembers, with the same system that is designed to provide protection from hypoxia. Technical Standard Order, TSO-C99, that was issued June 27, 1983, defines the standards for protective breathing systems that will serve this purpose. The TSO specifies maximum permissible contaminant leaks of 5 percent or less for the mask, and 10 percent or less for the goggles, or 5 percent or less for a full-face mask.

Providing protection for passengers from smoke and fumes is more complicated than for crewmembers. There are several complex questions which must be answered. Some of the questions asked concerning a device for passenger protection are: (i) Could the continuous-flow oxygen mask be adapted to provide this protection? (ii) Would a separate mask or other device be required? (iii) Since smoke could contain irritant gases, is it necessary to provide protection to the eyes, or is protection for the respiratory system, where fumes could be more life threatening, adequate?

Also, several steps are being proposed at this time to reduce the probability of uncontrolled in-flight fires; e.g., the addition of fire-blocking material to seat cushions, automatic fire extinguishers at lavatory trash bins, installation of smoke alarms at possible ignition sites, and additional hand-operated portable fire extinguishers. Considering these steps and the history of relatively infrequent occurrences of in-flight uncontrollable fires, is it necessary or economically feasible to develop additional breathing protection for passengers?

Table I presents a 10-year history of incidents involving smoke and fumes in the cabin or cockpit. Over this period, the number of incidents averaged just over 20 per year. On the average, about 13 per year were serious enough to warrant an emergency landing. Over this time, there were 24 fatalities. Twenty-three were from the Air Canada accident at Cincinnati (June 2, 1983). In a separate incident, one passenger set himself afire in a lavatory; it was determined that he died from carbon monoxide and smoke inhalation, not from burns. There were 3 passengers with serious injury (hospitalization); 17 passengers, 2 flight deck crewmembers, and 11 flight attendants exhibited minor smoke inhalation injury. There were also five flight deck crewmembers who suffered eye irritation without smoke inhalation. Even though it is apparent that the number of incidents of smoke or fumes in flight is small, the manner of

death in the fatality cases during this 10-year period indicates that there is a potential problem which warrants investigation.

TABLE I

Ten-Year History of Incidents Involving Smoke or Fumes in Cabin or Cockpit*

Year	Emergency Landing Made	No Emergency Declared	Unknown Status	Total Number of Incidents
1974	9	2	7	18
1975	11	1	4	16
1976	14	1	7	22
1977	11	8	2	21
1978	13	2	2	17
1979	19	3	2	24
1980	17	4	0	21
1981	9	7	1	17
1982	10	5	5	20
1983	17	9	4	30
TOTAL	130	42	34	206

*Source: The Civil Aeromedical Institute's Cabin Safety Data Bank.

In an earlier study conducted at this laboratory (2), several potential protective breathing devices for passenger use were tested for efficiency. One of the most promising was a standard passenger oxygen mask modified to incorporate a rebreather reservoir in addition to, but separate from, the oxygen reservoir. All prior tests for this device were conducted at ground level (about 1,300 ft at Oklahoma City) with subjects seated, without exercise. Under these conditions, it was determined that a sustaining oxygen flow of about 5 L/min, STPD (Standard Temperature Pressure Dry), would be required to provide oxygen and carbon dioxide levels within acceptable limits. It was recommended that additional studies be conducted at altitude to further verify the suitability of this device.

These further evaluations are herein reported; tests were conducted using a standard passenger mask with a rebreather bag added (Figures 1, 2, and 3). The major advantages of this system are: (i) It is a single system for protection from both hypoxia and fumes that would require only one stowage site and one set of donning instructions, and (ii) it would be relatively inexpensive (about $5) to retrofit an existing mask. The major disadvantages are: (i) It provides no protection for the eyes; (ii) it would require engineering modifications for some aircraft to activate the oxygen flow at normal cabin altitude pressures; and (iii) although the cost of the bag itself is modest, engineering modifications could be expensive and it could involve some additional stowage space involving additional cost. These follow-on studies were conducted in three phases.

PHASE I

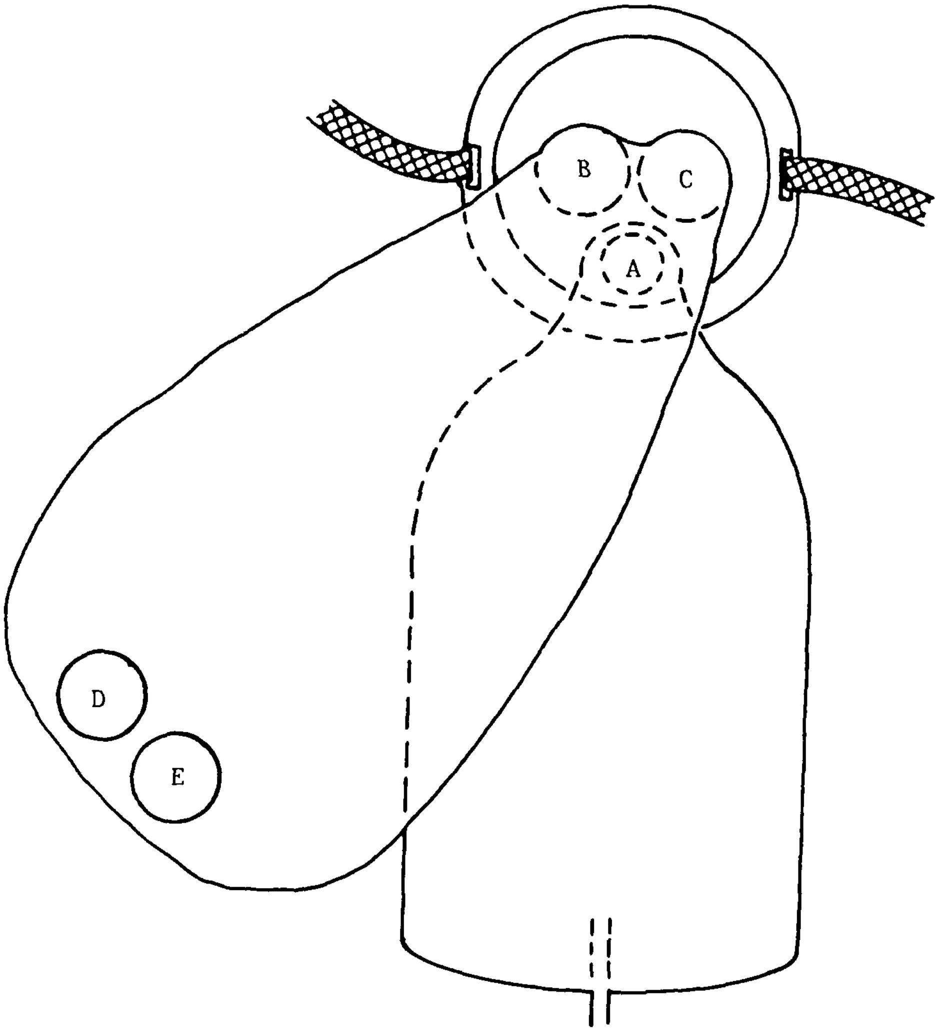
Methods

As originally designed, and as reported (2), this device worked quite well when the subject was seated quietly at ground level with oxygen flows of about 5 L/min, STPD, which is about 6 L/min, BTPS (Body Temperature Pressure Saturated). To test the device further, a workload of 50 watts was imposed to increase test subjects' respiratory exchange rate, since, on occurrence of an emergency, respiratory minute volume may increase due to anxiety or increased physical activity.

Subjects were required to pass a physical examination prior to minute volume determinations under exercise conditions. Accepted subjects reported at a later date for altitude tests. On the test day, they were given instructions on ear- and sinus-clearing techniques. Following this, an ear/sinus check was conducted by taking the altitude chamber to 6,000 ft equivalent altitude and returning to ground level at 3,000 ft/min. If test subjects could not clear their ears/sinuses readily, they were considered unsuited for the test. Subject 9 was disqualified at this point. If successful, they were fitted with chest electrodes for EKG and heart rate monitoring. The EKG was monitored on an electrocardiograph (Burdick EK-5A), and a simultaneous trace was continuously recorded on a polygraph (E & M Physiograph). The heart rate was also monitored on a heart rate meter that continuously averaged the preceding four beats (Burdick CSS-61). Subjects then put on a crew mask with a demand oxygen regulator and pedaled an ergometer set to impose the 50-W workload for a 10-min period. During this time, air samples were drawn from the mask for determining oxygen, nitrogen, and carbon dioxide levels. A respiratory mass spectrometer (Perkin Elmer MGA-1100) was used as the analytical instrument for measuring respiratory gases. It provided on-line analyses for oxygen, nitrogen,

Figure 1. Photograph of subject wearing passenger mask with rebreather bag added (front view).

Figure 2. Photograph of subject wearing passenger mask with rebreather bag added (side view).



A - Inhalation valve from the oxygen reservoir
B - Exhalation valve to the rebreather bag
C - Inhalation valve from the rebreather bag
D - Exhalation valve to ambient from rebreather bag
E - Inhalation valve to rebreather bag from ambient

Figure 3. Schematic drawing of passenger mask modified by the addition of a rebreather bag.

and carbon dioxide of each breath. A sample volume totaling 60 mL each minute was continuously drawn from the masks for gas analysis. Digital readouts for these gases provided continuous monitoring. A Honeywell Model 1858 fiber-optic oscillograph was used to produce high-speed analog recordings of the gas analyses from the mass spectrometer. After the exercise period, the mask was removed and subjects were given a 5-min rest period. Tests were terminated early if the heart rate exceeded 120 beats per minute for 1 minute or a transient peak heart rate exceeded 125 beats per minute.

Subjects then began the test with the passenger mask. Chamber-qualified FAA personnel accompanied test subjects during all chamber tests. The observer assisted the subject in obtaining a "best fit" of the passenger mask and ascertained that the correct sampling tube to the nose cone of the mask was in place. First, tests without exercise were conducted at ground level, 8,000 ft, 14,000 ft, and 21,500 ft. Oxygen flow to the mask was increased in increments of 1 L/min, BTPS (converted to STPD for altitude), until the rebreather bag remained distended and the end inspiratory partial pressure of carbon dioxide did not exceed 15 mm Hg pressure. After an adequate flow was established, 3 min of data were collected, and the chamber was taken to the next higher altitude. After the completion of the data-collection period at 21,500 ft with the subject at rest, data collection with the subject exercising was begun. While still at the maximum test altitude, subjects pedaled the ergometer at the 50-W load. The same two criteria were applied as for the rest condition to establish the correct flow. If the CO_2 level (percent of carbon dioxide) was too high, the flow was increased. However, if the flow was inadequate to prevent the rebreather bag from collapsing, we were unable to increase the flow quickly enough to reinflate the bag unless the subject stopped exercising. After each exercise period, subjects were given a 5-min rest period before collecting data at the next lower altitude. These data were collected in reverse altitude order; i.e., first at 21,500 ft, then at 14,000 ft, then at 8,000 ft, and finally at ground level.

Results and Discussion

Table II presents the minute volumes of the test subjects during the second, fourth, and sixth minutes of exercise on a bicycle ergometer set for 50 W and 50 rpm, during the pretest trials. This workload increased the minute volume to an average of 26.12 L/min during the sixth minute of exercise. Resting minute volumes for healthy adults will usually range from 3 to 10 L/min, with a mean of about 8 L/min (1).

Only 2 of the 10 subjects were able to maintain permissible oxygen and carbon dioxide levels to obtain a full

3 min of data collection during the exercise portion of the tests. The flows required for properly functioning masks

TABLE II

Minute Volumes (L/min) of Subjects Under a 50-Watt Workload

Subject No.	Minute 2	Minute 4	Minute 6
1	23.31	25.47	28.84
2	23.31	25.61	26.91
3	23.31	26.19	27.20
4	28.63	29.92	30.64
5	27.72	29.36	29.21
6	27.20	26.33	27.20
7	19.14	21.30	22.30
8	20.72	24.89	21.01
10	23.89	24.32	24.46
11	22.45	23.60	23.46
MEAN	23.97	25.70	26.12

while subjects were at rest are given in TABLE III. These data confirm those of the first study. Altitude had little effect on flow requirements. This is evidenced by converting the STPD flows at each altitude to BTPS flows. The mean BTPS flows ranged from 5.29 L/min at ground level to 5.58 L/min at 21,500 ft.

TABLE III

Acceptable Flows (L/min,STPD) - No Exercise

Subject	Altitude			
Number	Ground Level	8,000 ft	14,000 ft	21,500 ft
1	4.77	3.12	2.14	1.69
2	4.09	3.12	3.21	1.69
3	4.09	3.12	2.41	1.69
4	4.09	3.12	2.41	1.69
5	4.09	4.16	3.21	2.26
6	4.09	3.12	2.81	1.98
7	4.09	3.12	2.41	1.69
8	4.09	2.60	2.01	1.69
10	4.09	4.16	2.81	1.98
11	4.09	2.60	2.01	1.69
Mean, STPD	4.12	3.22	2.57	1.81
Mean, BTPS	5.29	5.39	5.56	5.58

When subjects increased their minute volumes by exercise, the device would not function properly, even with flows up to 11.28 L/min, BTPS. It appears that the cause of the malfunction is the inability of the valve into the rebreather reservoir to accept the increased flow. Only a portion of the exhaled air enters the rebreather bag, and the balance of each breath escapes around the outer edges of the mask. Also, the mask seals to the face better with inhalation than with exhalation. Thus, with only partial filling of the rebreather reservoir during exhalation and a more efficient emptying of the bag during inspiration, the volume of the reservoir declines with each succeeding breath until the reservoir bag is collapsed and the subject is unable to draw in any expired air. Additionally, incomplete filling of the reservoir does not allow any escape of the air through the distal end of the bag, therefore preventing the dilution of carbon dioxide. Table IV lists the flow for each subject during exercise at each altitude. Subjects 8 and 11 are the only ones for whom some adequate flows were attained. As shown in Table II, these two subjects were among those with the lowest minute volumes when exercising.

TABLE IV

Attempted Flows (L/min, STPD) - With Exercise

Subject	Altitude			
Number	Ground Level	8,000 ft	14,000 ft	21,500 ft
1	8.18*	**	**	**
2	8.18*	6.24*	4.82*	3.11*
3	6.81*	5.20*	4.02*	2.82*
4	**	6.24*	4.82*	3.39*
5	**	**	**	3.39*
6	**	**	**	3.39*
7	8.86*	6.76*	5.22*	3.39*
8	8.86	6.24*	4.82	3.66
10	8.86*	6.76*	5.22*	4.22*
11	8.86*	6.24*	4.42	3.11

* Maximum flow attempted - not adequate.
** Unable to collect sufficient data for flow determination.

PHASE II.

Methods

Two new designs of the mask with a rebreather bag were considered in Phase II. One design, which had a reduced-volume rebreather bag, did not function any better than the original design, and detailed testing was not conducted for it. The other design had the inhalation valve removed from the distal end of the rebreather bag so that ambient air

would not enter at this site, and the plastic seals were replaced with soft rubber seals to improve the seal of the rebreather bag to the mask. The same procedures were followed for the testing of this design as for those tested in Phase I, except that the verification testing at ground level was eliminated.

Results and Discussion

Table V presents the minute volumes, respiratory rates, and tidal volumes of subjects when they exercised on the bicycle ergometer at the 50-W workload. When tidal volumes were 1.59 L or higher, the masks did not function well. Either the buildup of carbon dioxide was unacceptable, the

TABLE V

Respiratory Data for Study of Redesigned Mask with Rebreather Bag

Subject Number	Minute Volume with Exercise (Liters)	Respiratory Rate with Exercise (Breaths/min)	Tidal Volume with Exercise (Liters)
2	23.6	23	1.03
4	22.0	18	1.22
5	18.5	14	1.32
7	27.5	20	1.38
1	22.8	16	1.43
9	23.8	15	1.59
3	19.8	11	1.80
8	18.8	10	1.88
6	17.8	9	1.98

For those subjects above the line, the redesigned mask worked well, requiring flows of only 5 to 6 L/min, BTPS. For those subjects below the dividing line, the redesigned mask did not work. Either the required flows of oxygen were too high, the buildup of carbon dioxide was unacceptable, the rebreather bag collapsed, or a combination of the failure criteria occurred.

rebreather bag collapsed, or a combination of these failures occurred, even when oxygen flows were increased to

excessively high and therefore unacceptable levels. Oxygen flows were considered as too high if they exceeded 7 L/min, BTPS, because the increase in cylinder drainage rate could cause the supply to be depleted too rapidly. As can be seen in this table, the tidal volume was a much more critical measurement than was the minute volume.

Table VI presents the flows and the pCO_2 (partial pressure of carbon dioxide) values for the subjects during rest. The upper limit for an acceptable pCO_2 is 15 mm Hg. Only subject 6, who had the highest tidal volume, produced an unacceptable pCO_2 when oxygen flows were limited to 5 L/min, BTPS. When the flow was increased to 6 L/min, BTPS, pCO_2 fell within acceptable values for Subject 6.

Table VII presents the same data for subjects during exercise. Those with the lower tidal volumes had satisfactory pCO_2 levels with low oxygen flows. Those with high tidal volumes had unacceptable pCO_2 levels with the exception of subject 6, for whom the rebreather bag collapsed before high pCO_2 levels were reached.

As with the first series of tests, it appears that when tidal volumes were high, the exhalation valve into the rebreather bag was not able to accommodate the high volume of air, and a part of the air escaped around the edge of the mask instead of into the rebreather bag. However, during inhalation, the mask has a better fit to the face, and the emptying of the bag is more efficient than the filling. This has two deleterious results. First, it does not allow enough air to enter the rebreather bag to force air out through the distal valve and, thus, allows the CO_2 to build up. Second, with the inefficient filling, and efficient emptying of the rebreather bag, the rebreather bag will eventually collapse.

PHASE III

Methods

To alleviate the suspected problem of restricted flow, possibly caused by an undersized exhalation valve into the rebreather bag or an exhalation valve with too great a resistance, three further modifications were made to the Phase II design. The first modification (identified as mask 3-I) was to increase the diameter of the valve opening, thereby increasing the surface area of the opening by 27 percent. The second modification (mask 3-II) was accomplished by punching four holes in the valve flapper. This allowed a 27-percent increase in total opening. The third modification (mask 3-III) was accomplished by punching the four holes in the valve flapper as was done for the second modification, in addition to increasing the surface area of the opening by 15 percent.

TABLE VI

pCO2 Values for Subjects While Using
Redesigned Masks - Without Exercise

Subj. No.	Exercise Tidal Volume (L)	8,000 ft Oxygen Flow (BTPS/STPD)	8,000 ft pCO2 (mm Hg)	14,000 ft Oxygen Flow (BTPS/STPD)	14,000 ft pCO2 (mm Hg)	21,500 ft Oxygen Flow (BTPS/STPD)	21,500 ft pCO2 (mm Hg)
2	1.03	5.0/3.0	1	5.0/2.3	1	5.0/1.6	1
4	1.22	5.0/3.0	2	5.0/2.3	1	5.0/1.6	1
5	1.32	5.0/3.0	2	5.0/2.3	1	5.0/1.6	1
7	1.38	5.0/3.0	1	5.0/2.3	1	5.0/1.6	1
1	1.43	5.0/3.0	2	5.0/2.3	1	5.0/1.6	1
9	1.59	5.0/3.0	2	5.0/2.3	8	5.0/1.6	6
3	1.80	5.0/3.0	8	5.0/2.3	8	5.0/1.6	3
8	1.88	5.0/3.0	15	5.0/2.3	11	5.0/1.6	2
6	1.98	5.0/3.0	19*	6.0/2.8	8	6.0/2.4	3

* pCO2 too high, BTPS flow increased for next altitude.

TABLE VII

pCO_2 Values for Subjects While Using Redesigned Masks - With Exercise

		8,000 ft		14,000 ft		21,500 ft	
Subj. No.	Exercise Tidal Volume (L)	Oxygen Flow (BTPS/ STPD)	pCO_2 (mm Hg)	Oxygen Flow (BTPS/ STPD)	pCO_2 (mm Hg)	Oxygen Flow (BTPS/ STPD)	pCO_2 (mm Hg)
2	1.03	5.0/3.0	5	6.0/2.8	2	7.0/2.3	1
4	1.22	5.0/3.0	2	5.0/2.3	1	5.0/1.6	4
5	1.32	5.0/3.0	11	5.0/2.3	5	5.0/1.6	1
7	1.38	5.0/3.0	3	5.0/2.3	1	5.0/1.6	1
1	1.43	5.0/3.0	1	5.0/2.3	4	5.0/1.6	2
9	1.59	6.0/4.2	11	6.0/2.8	19	5.0/1.6	8
3*	1.80	7.0/4.8	10	8.0/3.7	20	6.0/2.0	16
8*	1.88	9.0/6.0	11	9.0/4.2	16	6.0/2.0	23
6**	1.98	9.0/6.0	1	10.0/5.1	1	8.0/2.4	7

* Less than 1 min recorded before pCO_2 reached unacceptable value or the rebreather bag collapsed.

** Rebreather bag collapsed before pCO_2 reached unacceptable value.

The same protocol for testing was followed as for Phase II, except that during the initial testing (masks 3-I, 3-II, and 3-III) for Phase III, only subjects with high tidal volumes were studied.

Results and Discussion

Mask 3-II, which had only the punched holes in the valve flapper, did not prove to be any more efficient than previous designs. Masks 3-I and 3-III ameliorated the problem of the rebreather bag collapsing but did not provide an adequate reduction to the buildup of CO_2.

One reason that the CO_2 continued to build up in these masks could be that the reduced resistance at the valve into the rebreather bag was not accompanied by a concomitant reduction in the resistance of the escape valve at the distal end of the rebreather bag. Thus, there was an inadequate amount of air moved out to the ambient atmosphere. To reduce the resistance of the valve at the distal end of the rebreather bag, the loading spring was removed and one-half the length cut off before replacing it. This additional modification was made on both the first and third designs described above, now designated as mask 3-I-4 and mask 3-III-4, respectively. They were tested with both high and low tidal volume subjects.

The results of the tests with these two modified masks are presented in Table VIII (for mask 3-I-4) and Table IX (for mask 3-III-4). The results present mixed findings. With both masks, one low tidal volume subject exhibited acceptable results at the 5 L/min, BTPS, flow both at rest and with exercise. However, good results were obtained with the low tidal volume subjects before any modifications were made. Most of the unacceptable results were caused by unsatisfactory pCO_2 levels. There were no instances of the rebreather bag collapsing with the mask that had the surface area of the exhalation valve into the rebreather bag increased by 27 percent (mask 3-I-4).

CONCLUSIONS

Results to date indicate that the continuous-flow passenger mask to which a rebreather bag is added still has the potential for providing protection from smoke and fumes for the wearer. However, the system must have appropriately balanced resistance and appropriately sized valve openings. This critical balance has not yet been achieved for subjects with a wide range of breathing patterns and with large tidal volumes.

TABLE VIII

Results of Tests of Mask 3-I-4

Condition	Oxygen Flow (L/min, BTPS) 8,000 ft			14,000 ft			21,500 ft		
	5	6	7	5	6	7	5	6	7
Without Exercise									
Subject 1-L	*	-	-	*	-	-	*	-	-
7-L	*	-	-	*	-	-	*	-	-
2A-L	CO_2	CO_2	*	*	-	-	*	-	-
3A-H	MCO_2	-	-	MCO_2	-	-	CO_2	-	-
8-H	*	-	-	*	-	-	*	-	-

Condition	21,500 ft					14,000 ft				8,000 ft			
	5	6	7	8	9	5	7	8	9	5	6	7	9
With Exercise													
Subject 1-L	*	-	-	-	-	*	-	-	-	*	-	-	-
7-L	CO_2	-	-	CO_2	-	-	-	-	*	-	-	-	CO_2
2A-L	-	CO_2	-	-	CO_2	-	-	-	CO_2	-	-	-	CO_2
3A-H	-	-	-	CO_2	-	-	-	-	CO_2	-	-	-	CO_2
8-H	*	-	-	-	-	CO_2	*	-	-	-	CO_2	CO_2	*

Legend:
* indicates acceptable results.
- indicates no measurements made.
CO_2 indicates unacceptable carbon dioxide level.
MCO_2 indicates marginally acceptable carbon dioxide level.
-H indicates a high tidal volume subject (greater than 1.5 L).
-L indicates a low tidal volume subject (less than 1.5 L).

TABLE IX

Results of Tests of Mask 3-III-4

Condition	Oxygen Flow (L/min, BTPS) 8,000 ft			14,000 ft			21,500 ft		
	5	6	7	5	6	7	5	6	7
Without Exercise									
Subject 2-L	*	-	-	*	-	-	*	-	-
4-L	*	-	-	*	-	-	*	-	-
3-H	*	-	-	*	-	-	*	-	-
5-H	*	-	-	*	-	-	*	-	-
6-H	*	-	-	*	-	-	*	-	-

Condition	21,500 ft					14,000 ft				8,000 ft			
	5	6	7	8	9	5	7	8	9	5	6	7	9
With Exercise													
Subject 2-L	CO_2	-	CO_2	-	CO_2	-	-	-	CO_2	-	-	-	CO_2
4-L	*	-	-	-	-	*	-	-	-	*	-	-	-
3-H	CO_2	-	-	-	CO_2	-	-	CO_2	-	CO_2	CO_2	-	*
5-H	*	-	-	-	-	BC	-	-	-	-	CO_2	-	-
6-H	MBC	-	-	-	-	MBC	-	-	-	CO_2	MBC	-	-

Legend:
- * indicates acceptable results.
- \- indicates no measurements made.
- CO_2 indicates unacceptable carbon dioxide level.
- BC indicates collapse of rebreather bag.
- MBC indicates rebreather bag moving toward collapse.
- -H indicates a high tidal volume subject (greater than 1.5 L).
- -L indicates a low tidal volume subject (less than 1.5 L).

REFERENCES

1. Consolozio CF, Johnson RE, Pecora LJ. Physiological measurements of metabolic functions in man, p.196. New York: McGraw-Hill, 1963.

2. deSteiguer D, Saldivar JT. An Analysis of potential protective breathing devices intended for use by aircraft passengers. Report No. FAA-AM-83-10. Washington, DC: Federal Aviation Administration, Office of Aviation Medicine, 1983.

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